The need for reconfigurable DC electricity networks

A Policy Brief, for the project “Reliable, Reconfigurable DC Distribution Networks” (R2D2-NET)

Electricity network transformation has been in the forefront of research and industrial development for at least a decade. Multiple approaches have been proposed. The concept of Smart Grids has emerged in the beginning of this century, as a solution that would enable an ageing infrastructure to maintain its safe and cost-effective operation throughout the decades to follow. Large load and generation changes were forecasted, and making the power system adaptable, “smart” and highly controllable became some of the key goals.

However, there are technologies that show great promise but have been receiving very little attention. One of those technologies is electricity distribution using Direct Current (DC), rather than the usual Alternating Current (AC). This document presents the key advantages of this technology, as well as the ways that it can be integrated into current Smart Grid efforts.

1. DC networks instead of AC in the community

The approach of replacing AC networks with DC networks has been proposed and discussed in the industry for several years. There are technical barriers but also advantages. A large driver for such a shift would be the demand side. The nature of electricity demand is changing, with electric vehicles being responsible for the single largest shift. Electric vehicles are inherently DC devices, since they charge and discharge a large battery. In order to do that through an AC grid, they require expensive and relatively inefficient AC/DC or DC/AC converters. These converters are based on power electronics and, whereas technology has advanced to the stage that losses are not large, they are still measurable and not insignificant. In addition, they can introduce harmonic distortion to the power system, which creates other problems. Many of the fast- and superfast-charging devices in development are also based on DC supply directly to the battery. If these devices are supplied by a centralized DC supply, there is an immediate saving to be had, from the lack of comparatively large AC/DC converters. DC charging forecourts and other multi-charger systems have been proposed, and the local network supplying those chargers could possibly be a DC network.

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Apart from the demand, the other key factor is the supply. Renewable energy at the local / community scale is dominated by domestic photovoltaics (PV), which generate DC electricity. They require a power electronics inverter to convert their output to AC, suitable for consumption through the AC grid, or even locally. When PV generation is consumed locally, in the same household, it needs to be converted to AC, then back to DC to supply things like consumer electronics, thus wasting a significant part of the generated energy. This is one of the key arguments for domestic, or at least community-level, DC systems.

Finally, when considering DC distribution networks, these have technical advantages against AC networks. One such advantage is that they do not need to compensate for reactive power. Reactive power is a peculiarity of AC networks, and essentially oscillates between the generator and the load. Inductive loads like induction motors need reactive power, which creates the need for compensating schemes, in order to maintain efficient and safe network operation. In DC networks, these compensators are unnecessary.

The above arguments are summarized in Table 1.

Table 1. Advantages and disadvantages of DC and AC networks

DC	AC
Advantages	**Advantages**
Direct supply to certain DC loads, like Electric Vehicles	High-efficiency transformers to convert to different voltage levels
Direct interconnection of domestic photovoltaics and battery installations without the need for DC/AC converters	Established technology
No need for reactive power compensation	Less complexity in control of power flows
Disadvantages	**Disadvantages**
Some DC loads will still need DC/DC converters, which can have efficiency disadvantages	Requires conversion of AC to DC for DC loads, which are increasingly popular, e.g. Electric Vehicles
More difficult to control voltage and power flow	Requires conversion of DC to AC for photovoltaics and batteries, which are expected to play a significant role In future homes
New technology, not widely tested	Reactive power compensation schemes are required at certain points in the network

2. Challenges and opportunities of DC networks

Despite their advantages, DC networks come with certain challenges. The most significant of those being as follows.

- AC networks have been developed, installed and refined over several decades. In order for DC networks to reach the same maturity, it would take considerable time and expense.
- Whereas in AC networks it is relatively straightforward for the voltage to step up or down with transformers, in DC networks this requires a DC/DC converter. Transformers are simple electromagnetic devices that could

operate for decades with minimal maintenance, but DC/DC converters are complex power electronics devices, which are more prone to problems.
- The control of voltage in AC networks can be done through established techniques, like using reactive power. In DC networks, some of those techniques are not available, which means that generators and power electronics converters must perform that function, which is more difficult.

Still, there are certain opportunities available when considering the introduction of DC networks.

- Being a new technology, they are free of the burdens of existing AC networks and ageing equipment. There is no need to replace the whole grid with a new "version", but there is certainly scope for hybrid AC and DC operation.
- DC networks, as a relatively recent technology, offer greater flexibility to adapt new installations to the needs of current demand and generation, and become future-proof through innovation.
- Local DC networks can support the development of green technologies such as electric vehicles and renewable energy.

3. Reconfiguration of DC networks to enhance their controllability

The aim of this project has been to consider the capability of DC networks to be reconfigured, in order to re-route power through different pathways. This can present advantages in the technical operation of the distribution network and has been an active research field for AC networks for some time.

Reconfiguration in power distribution relates to distribution cables that are normally inactive, but can be re-connected remotely, to alleviate congestion or other adverse conditions in other parts of the network. For instance, when a particular distribution line becomes overloaded by too many consumers, an alternative route can be activated, so that part of this power is delivered through a different cable, alleviating congestion. More subtle operational parameters can also be controlled in the same way, such as voltage levels. Voltage levels can vary across the network and they need to be maintained within certain statutory limits at all times. Reconfiguration can alter the operation of the network so that voltages across the network are always maintained within those limits.

The above functionality enhances the controllability of the distribution network. In particular, for DC networks, it can cancel out some of their disadvantages, such as the lack of reactive power control.

4. Policy considerations

Whereas most of the developments that are necessary for DC network deployment are technical, there are certain areas where policy can become the catalyst for implementing these technological innovations and help realise the benefits of DC networks. The following sections present certain suggestions for such policies.

a. Policies for overcoming technical challenges

There are several startup companies exploring the feasibility and benefits of DC technologies. Some of them are very successful and they are generally focused on renewable energy (e.g. solar PV), domestic batteries or electric vehicle chargers.

Support for such startups is crucial for their success, as these are unproven technologies that require a lot of investment in order to gain consumer confidence and the necessary growth. These innovators will provide the local equipment platform on which DC networks can be based.

b. Policies to encourage uptake

Incentives to support uptake of DC devices and technologies are also important, since many of these technologies will not have been tested as widely as AC technologies.

Policies such as the Green Deal can provide the necessary incentives for early adopters to invest in these technologies and fuel their uptake.

c. Policies to support network operators

Network operators are generally reluctant to deviate from their established operating norms, since their focus is day-to-day power delivery to their customers. Many of them are keen to innovate, but this is typically at higher TRL levels, with established and proven technologies.

Incentives such as the Network Innovation Competition / Allowance can be employed to drive the network operators towards adopting DC technologies, proving their effectiveness and creating a niche in the power market.

d. Policies to support the integration of reconfigurable DC networks in the power industry

Reconfigurable DC networks require functional DC networks, and this needs to happen first. However, the energy industry is currently evolving towards the Smart Grid paradigm, which includes many new concepts, such as Active Network Management (ANM), or resource aggregation.

ANM techniques for AC networks are advanced in the TRL scale and Distribution Network Operators (DNO) are undertaking trials for testing their operation in real environments. They generally aim to improve the operational parameters of the grid, in a similar way to what has already been described above regarding DC network reconfiguration. Hence, the policies for the network operators can also aim towards encouraging realistic tests of DC reconfiguration technologies.

Finally, aggregators are entities that aggregate resources, mainly for energy trading, but they can also be set up for different purposes, like DC resource aggregation.

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